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EXAMINATION OF ONBOARD TRAINING FOR EXTENDED SPACE FLIGHTS

by Richard Reid and R. T. Saucer

Langley Research Center
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SUMMARY

A method with small weight and volume requirements for maintaining pilot skills for extended space flights was studied. The method makes use of onboard displays, controls, and attitude fuel without degrading the over-all system reliability.

The method uses electronically generated disturbance signals which are summed with manual control inputs to the attitude stabilization system. The disturbance signals create perturbations on the spacecraft. The pilot then obtains real training by controlling the attitude of the spacecraft in the presence of the perturbations.

Since the disturbance-signal generation requires insignificant weight and volume, the system was evaluated for attitude-fuel requirements in terms of training time available. Two attitude control tasks were performed with random disturbance signals representing a force approximately equal to one-third the manual control force applied to all three axes. The results of the study indicate that approximately 2 pounds of attitude fuel per minute of training are required to perform the tasks at this level of disturbance.

INTRODUCTION

A projection of the goals of present manned-space-flight programs leads to the conclusion that long missions will be made in which the pilot must perform complex tasks after long periods of idleness. A high level of proficiency in these complex tasks must be maintained throughout the flight despite possible physiological and psychological stresses which would tend to reduce pilot proficiency.

The purpose of this study was to examine a method of in-flight training which requires small weight and volume additions to the spacecraft and does not degrade the over-all system reliability. The method uses electronically generated random signals to represent external disturbances to the spacecraft. The pilot's task is to perform prescribed attitude maneuvers in the presence of the disturbances.

The concept was studied with a three-axis moving-base simulator and was evaluated on the basis of attitude fuel required per minute of training.

SYMBOLS

$T_\psi, T_\theta, T_\varphi$	total effective thrust producing rotation about X-, Y-, and Z-axis, respectively, lb
X,Y,Z	body axes of vehicle
ψ, θ, φ	yaw, pitch, and roll of vehicle, positive up and right, deg
$\dot{\psi}, \dot{\theta}, \dot{\varphi}$	time rate of change of ψ, θ, φ, respectively, deg/sec

GENERAL CONSIDERATIONS

The problem is to devise equipment and procedures which will provide real and useful in-flight training without degrading the reliability of flight control systems or imposing excessive weight and volume requirements. Three approaches to mechanizing onboard simulation systems for attitude control training are discussed.

One approach was to design a packaged simulation system which would provide the desired exercise. Through use of state-of-the-electronics-art components, a reliable miniaturized system suitable for in-flight training was designed and built for the Mercury spacecraft. This three-degree-of-freedom system simulated the Mercury equations of motion in restricted form and displayed the vehicle rates on a display identical with the in-flight display. The main components of the system were a special-purpose analog computer with random inputs, self-contained power supply, and a scoring device. These instruments were mechanized within an envelope of less than $\frac{1}{4}$ cubic foot and less than 10 pounds of weight. Over-all system reliability was not degraded by inclusion of the training device since the only interface with the spacecraft system was the set of relays which disconnected the device from the telemetry system when it was not being used. In spite of a gross weight of less than 10 pounds, the device was not used because of the weight factor.

A second approach considered was the design of a system which would be less weight critical. Analysis of the Mercury simulation system indicated that a significant reduction in weight would have been possible if onboard displays and power supply had been used. These savings together with the weight reduction obtainable by substituting an electronic random noise generator for a solenoid-operated electromechanical signal generator would have reduced the weight to less than 5 pounds. This approach, however, raised a problem more critical than the problem of weight. The use of onboard displays requires the multiplexing of displays and controls between the simulator and the spacecraft flight system. For reasons of flight safety such an approach is questionable unless the spacecraft systems are designed and perhaps qualified for flight with such a requirement in mind.

It is seen in these two approaches that both weight and the effect of the simulator on flight systems reliability are constraints on the design of in-flight training methods. The development of a system with the reliability of the first system and the low weight of the second system appears desirable. This third approach was examined in this study.

The essential feature of this method is a disturbance signal which is generated and summed electronically with the control signal. The difference between these signals is then the input to the attitude control system of the spacecraft. Rates and attitudes will be generated exactly as though the spacecraft were responding to the difference between the two real physical forces. Such difference or error rates and attitudes would be sensed and displayed on existing spacecraft instruments. The pilot is thus provided real training without weight penalty or degrading the over-all system reliability.

APPARATUS

The problem was studied with the three-axis cockpit used in the Langley rendezvous docking simulator (fig. 1). Control was obtained with a three-axis, on-off, side-arm controller. Thrust level was 10 pounds for all three axes with accelerations of 2.70, 1.80, and 1.83 deg/sec^2 in roll, pitch, and yaw, respectively. The equations of motion programed on an analog computer were those of reference 1 for three degrees of freedom with no thrust misalinement, no inertia coupling in roll, and no damping augmentation. Cockpit displays were a two-axis 8-ball for roll and pitch and a dial indicator for heading. Roll, pitch, and yaw rates were displayed on a three-axis needle instrument. A drawing of the instruments is shown in figure 2.

Figure 3 is a block diagram of the elements in this simulation. The position instruments displayed a measurement of the vehicle position while the rate instruments were driven by the output of the equations of motion. The disturbance signals that were summed with pilot control in each axis were obtained by filtering the output of Gaussian noise generators. The filters consisted of two first-order lags with break frequencies at approximately 1 radian per second. The root-mean-square amplitude of the filtered noise was set at one-third of the pilot control force. Figure 4 is a sample of the three-axis random noise.

PROCEDURES

Three subjects were used in the study: two experienced NASA test pilots (subjects A and B) and an NASA engineer with piloting experience (subject C). Each subject performed the following three tasks:

1. Hold zero attitude with disturbance in all three axes.

2. Roll right 15° and hold 1 minute, roll left 15° and hold 1 minute, position at zero and hold 1 minute with no disturbance.

3. Same as task 2 with disturbance in all three axes.

Each subject made a sequence of 10 runs: three runs of task 1 to determine fuel required to null the disturbance, three runs of task 2 to determine fuel required to perform the roll maneuvers, three runs of task 3 to determine fuel required to perform the roll maneuvers while nulling the noise, and then one run of task 1 to determine any improvement in performance and fuel use.

No instructions were given to any of the subjects regarding accuracy of control or minimizing fuel consumption.

RESULTS AND DISCUSSION

Since the method requires small weight and volume additions to the spacecraft, the most important parameter is the use of attitude fuel in performing the tasks. Table I shows the fuel rates for the different subjects performing a sequence of runs for the different tasks. The experienced test pilots (subjects A and B) showed a continuing reduction in fuel used with an average of slightly less than 2 pounds of fuel per minute of control. The addition of roll maneuvers required no additional fuel, although the subject's comments indicated an increase in the degree of difficulty. The engineer (subject C) showed a decrease in performance from a fuel-usage standpoint. The comments of subject C indicate that the increase in fuel consumption was caused by concentrating on precise control of the vehicle's attitudes without regard to fuel usage.

Figures 5, 6, and 7 are time histories of attitude, velocity, and total effective thrust, respectively, for task 1. The records for task 1 indicate that continuous control is required to maintain attitudes within 5°, and there were excursions twice this value. This result indicates that the amplitude and frequency of the disturbance was close to the maximum that would be usable for training in terms of the system control force. Therefore, the fuel-usage rate shown in table I would probably be reduced by using a lower disturbance level.

Figures 8, 9, and 10 are included to indicate pilot techniques in performing the roll maneuvers without disturbance (task 2). Figure 8 indicates that the control requirement is small and table I shows the associated low fuel usage.

The result of adding disturbance to task 2 is presented in figures 11, 12, and 13 (task 3). A comparison of these results with those of figures 5, 6, and and 7 indicates that the control task is more difficult resulting in larger excursions in attitude. Subjects A and B used less fuel in task 3 than in task 1, with better than a 15-percent reduction in fuel used when task 1 was repeated at the end of the sequence. Subject C used a considerably larger amount of fuel for task 3, with a 36-percent increase in fuel used when task 1 was repeated at the end of the sequence.

The results showed that the method is workable, has value for training, and will require minimal additions to the spacecraft. The subjects' opinions varied on the degree of difficulty of the task but none of the subjects indicated that the task required full effort. All subjects agreed that the system could prove useful in maintaining pilot skills.

CONCLUDING REMARKS

A method using onboard displays, controls, and attitude fuel as a means for maintaining pilot skills during extended space flights was studied. Although training time available with this system would be limited by onboard fuel, the method has the following distinct advantages over the other approaches to in-flight training:

1. Weight and volume requirements are small.

2. Using the spacecraft display, sensor, and control system provides a dynamic simulation which is real rather than merely realistic.

3. Minimized interfaces between simulation and flight control equipment provide minimum reduction in over-all flight reliability.

4. Safety margin is provided in that the simulator need only be used when sufficient onboard fuel is available with little penalty in additional spacecraft weight.

The study indicated that attitude-fuel requirements would be large for extended training periods. However, the system could prove useful in training for specific short-duration tasks after long periods of idleness.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 8, 1964.

REFERENCE

1. Brissenden, Roy F.; Burton, Bert B.; Foudriat, Edwin C.; and Whitten, James B.: Analog Simulation of a Pilot-Controlled Rendezvous. NASA TN D-747, 1961.

TABLE I.- FUEL RATES FOR DIFFERENT TASKS

Subject	Task	Number of runs per task	Average fuel rate, lb/min
A	1	3	2.20
	2	3	.24
	3	3	1.77
	1	1	1.77
B	1	3	1.89
	2	3	.26
	3	3	1.73
	1	1	1.56
C	1	3	1.50
	2	3	.38
	3	3	2.17
	1	1	2.04

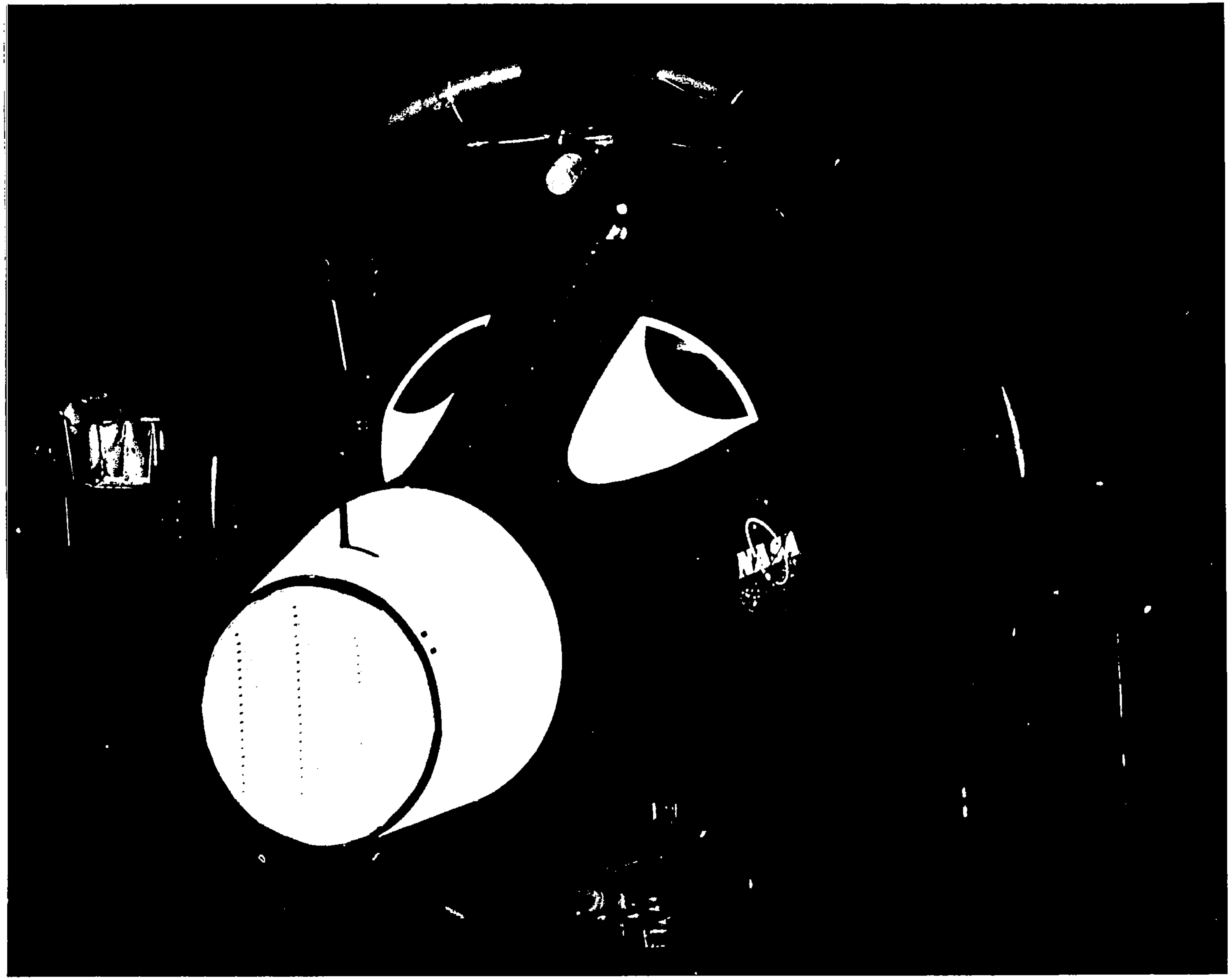


Figure 1.- Three-axis cockpit used in the study. L-64-4747

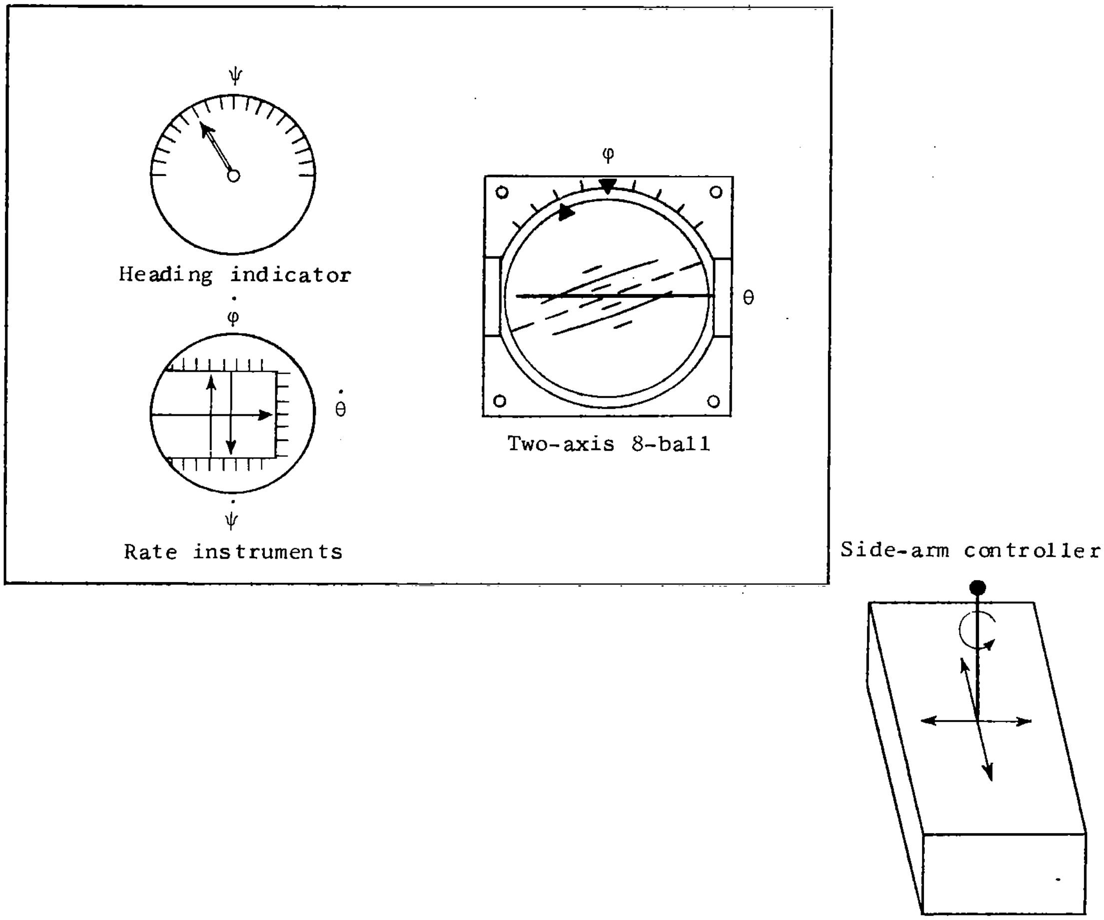


Figure 2.- Pilot display and side-arm controller.

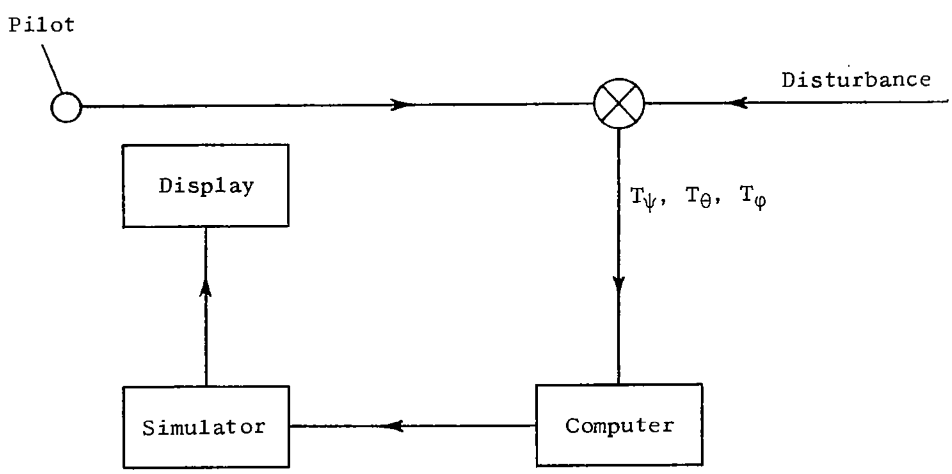


Figure 3.- Block diagram of simulation.

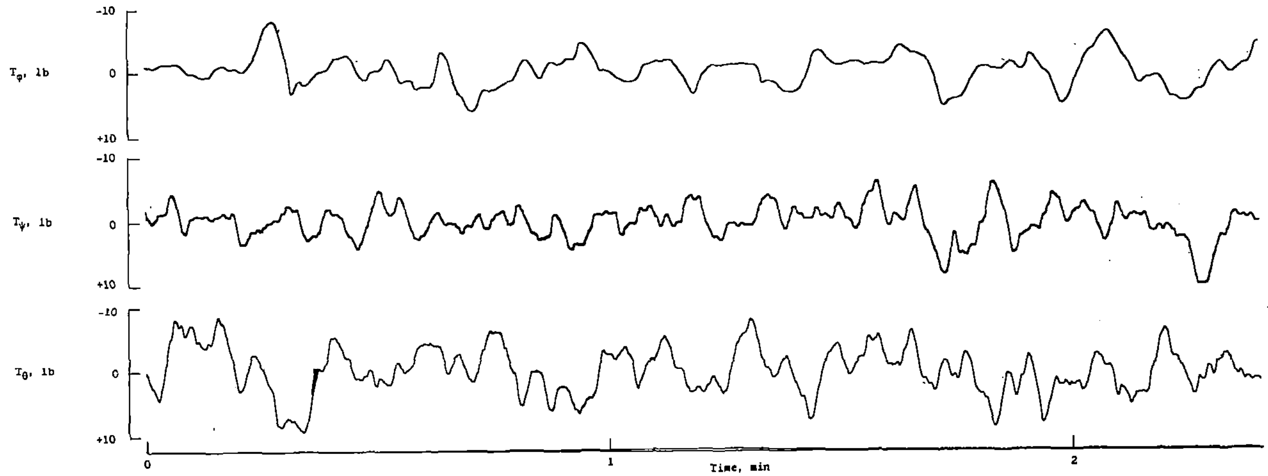
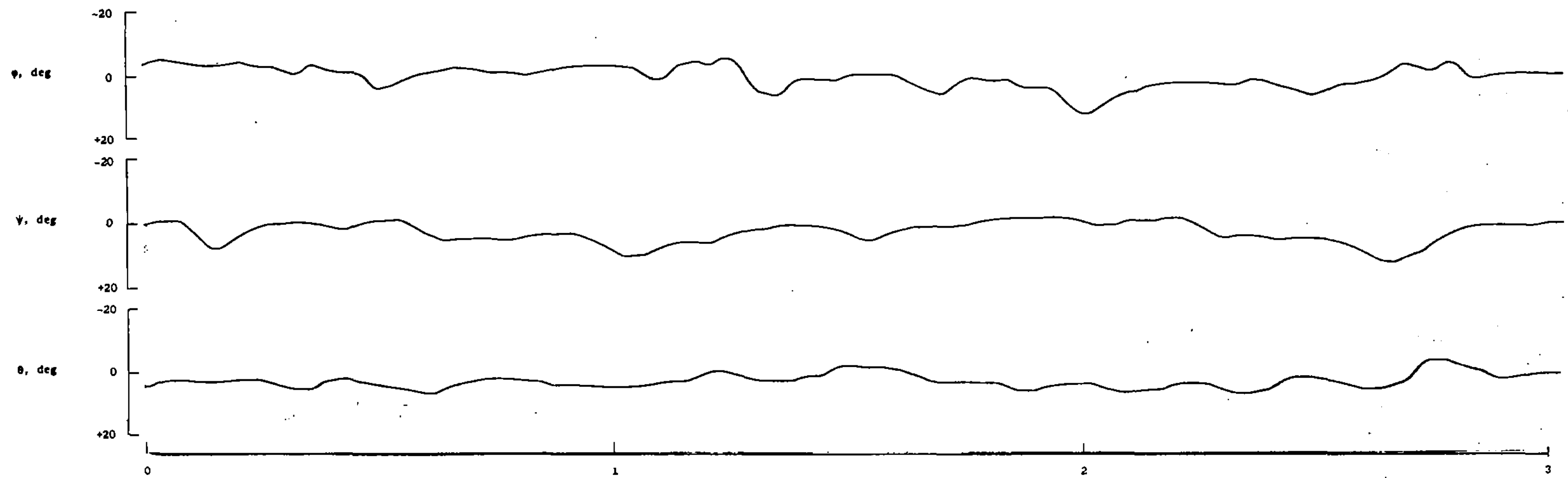
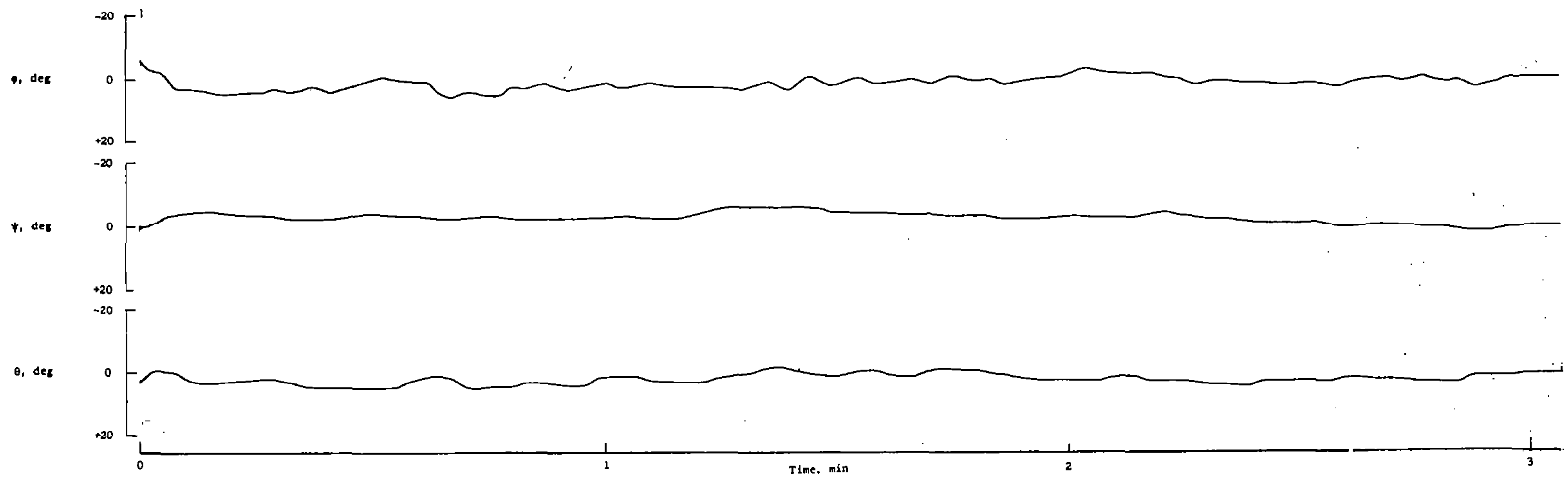


Figure 4.- Sample of three-axis random noise.

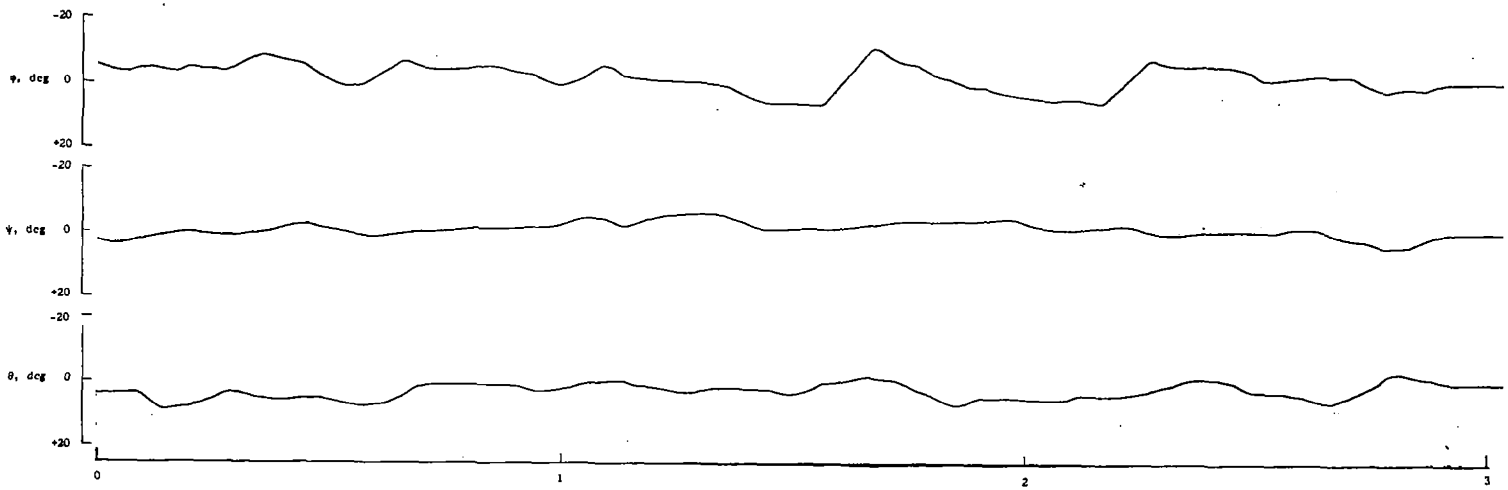


(a) Pilot A.



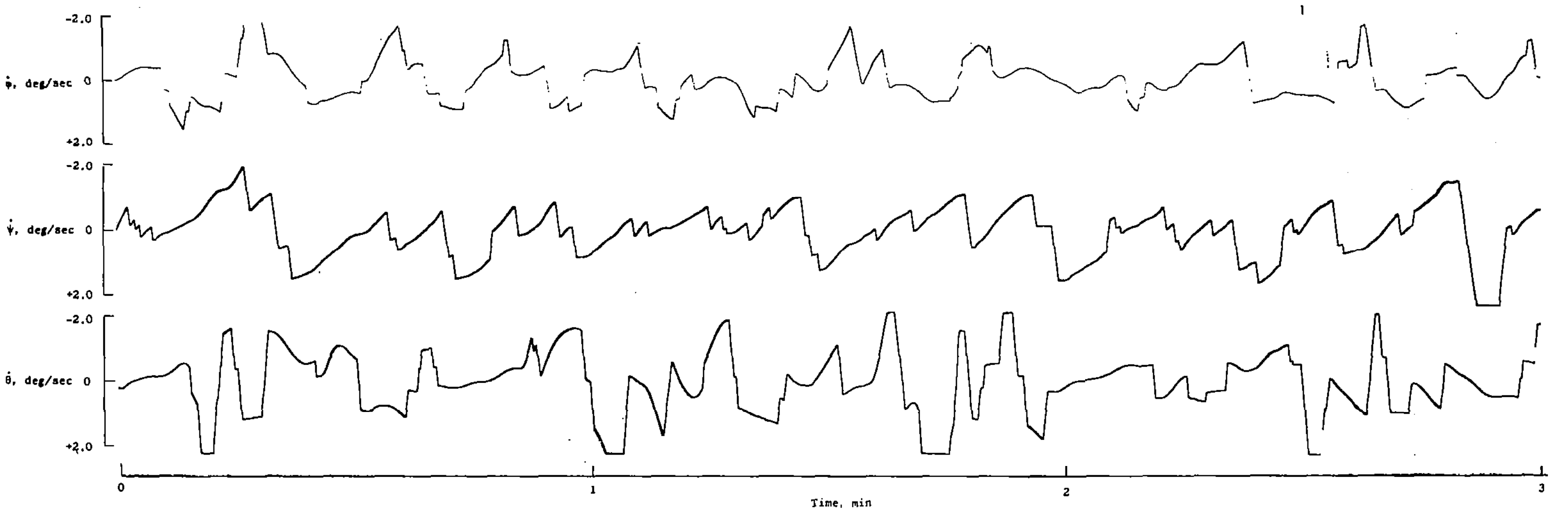
(b) Pilot B.

Figure 5.- Variation of attitude with time for task 1.

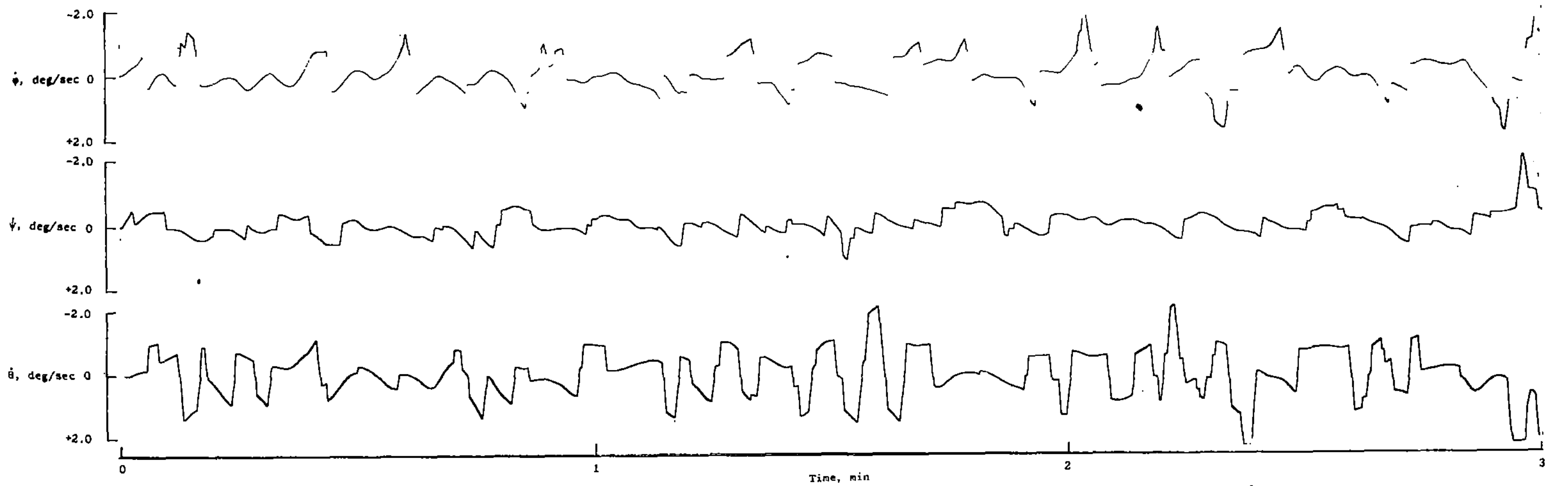


(c) Pilot C.

Figure 5.- Concluded.

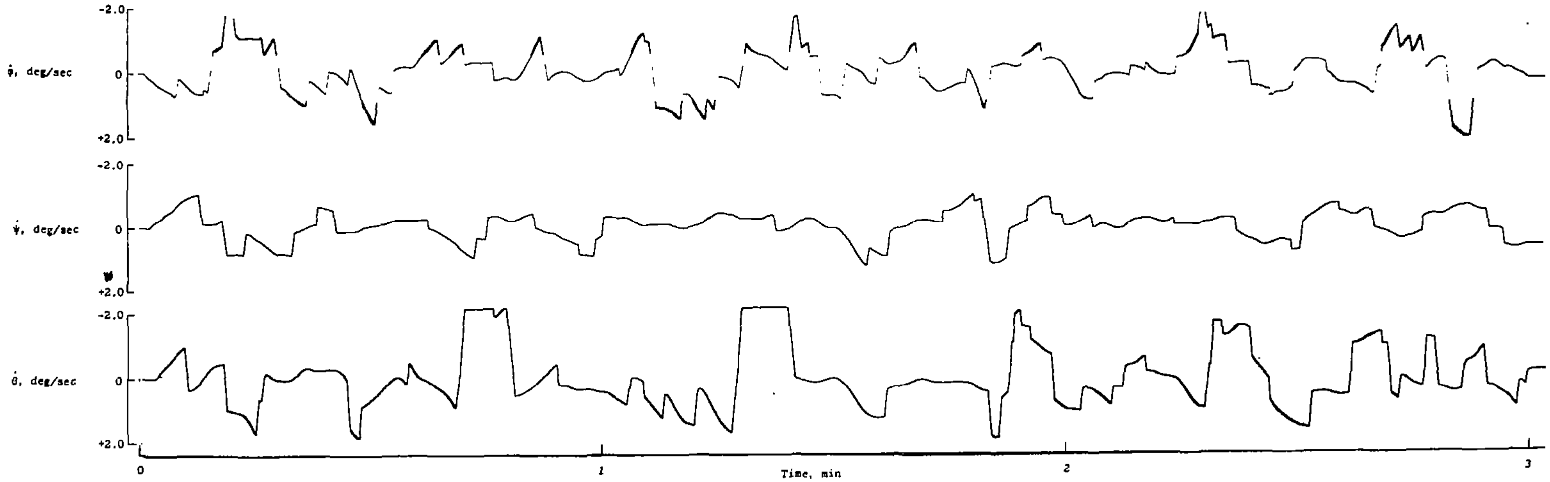


(a) Pilot A.



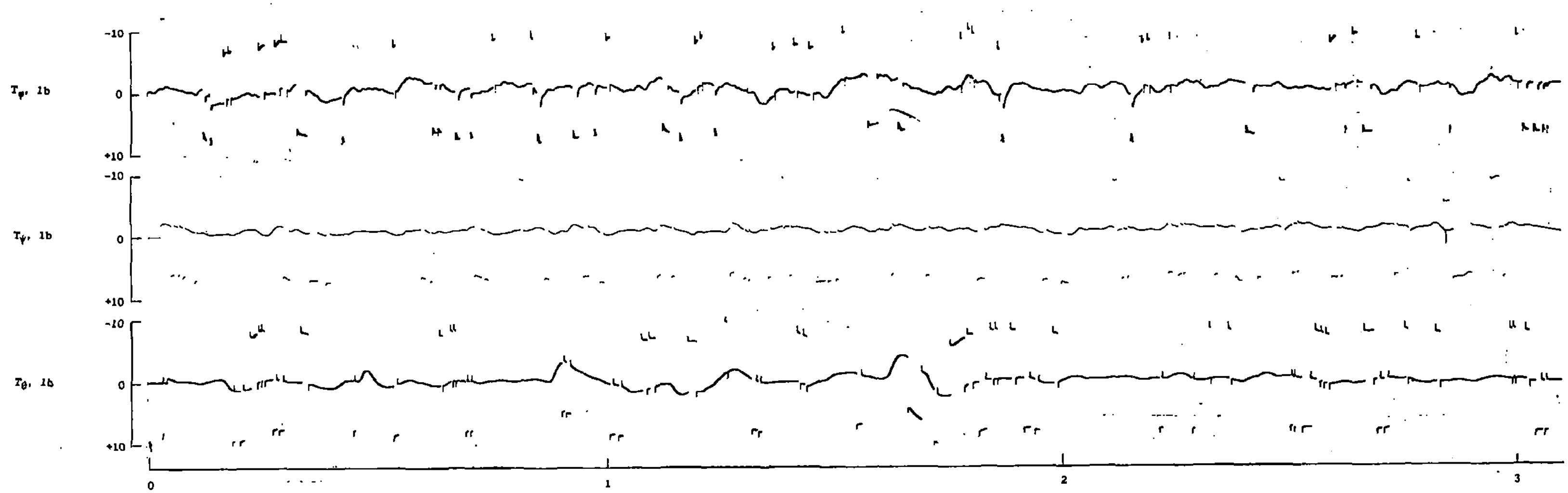
(b) Pilot B.

Figure 6.- Variation of angular velocity with time for task 1.

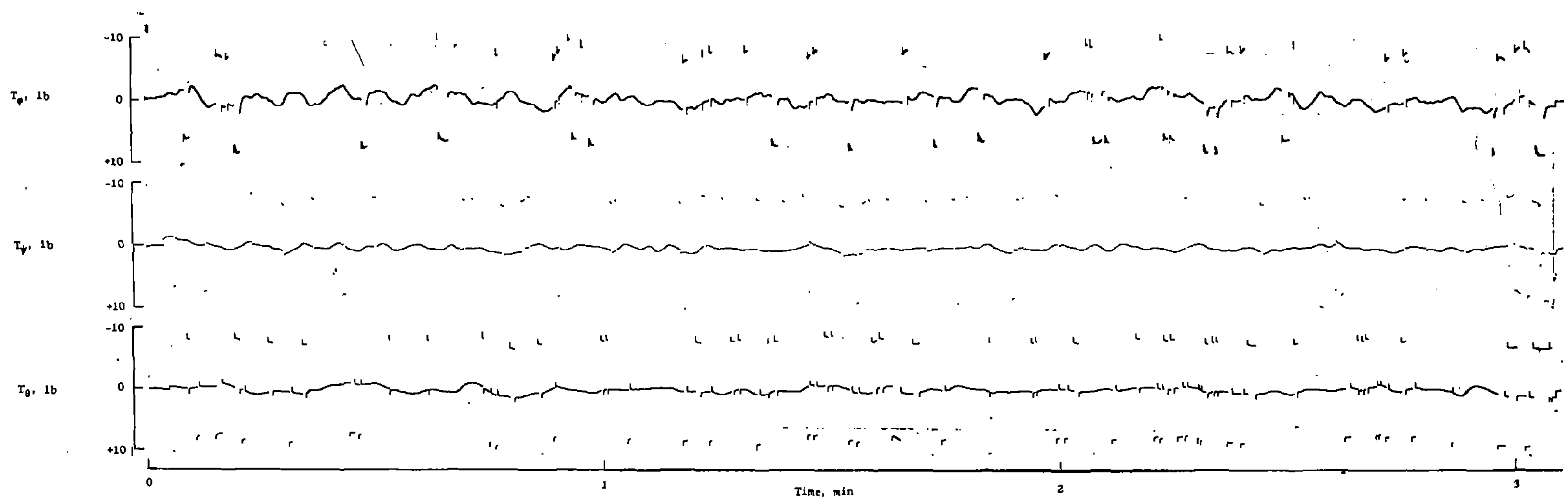


(c) Pilot C.

Figure 6.- Concluded.

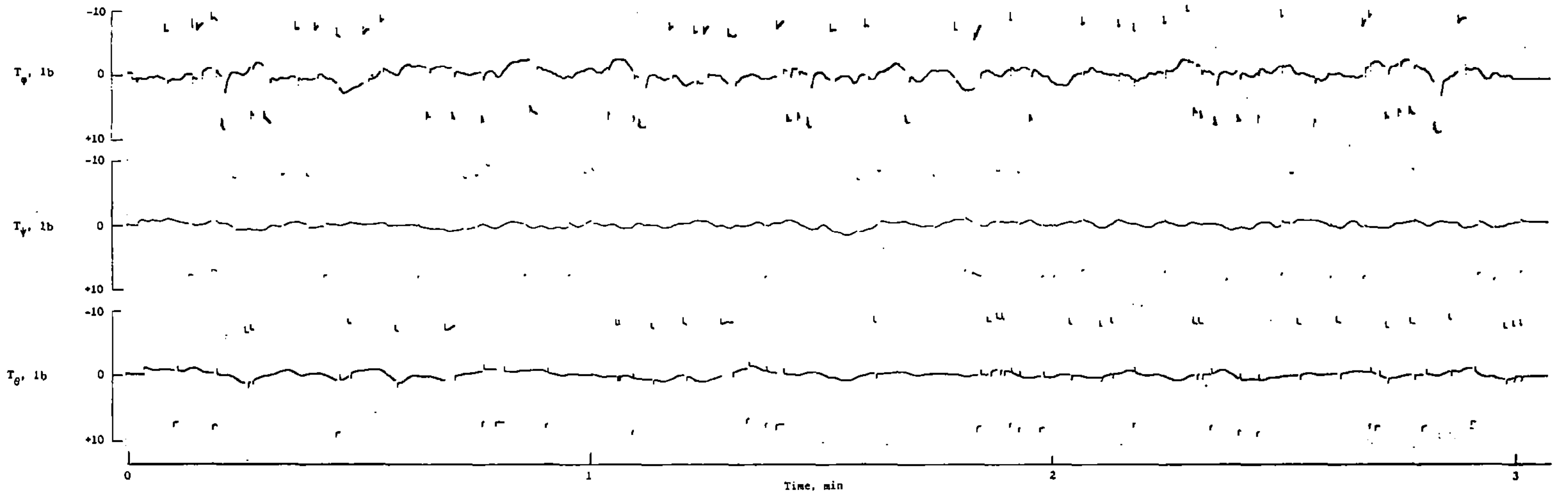


(a) Pilot A.



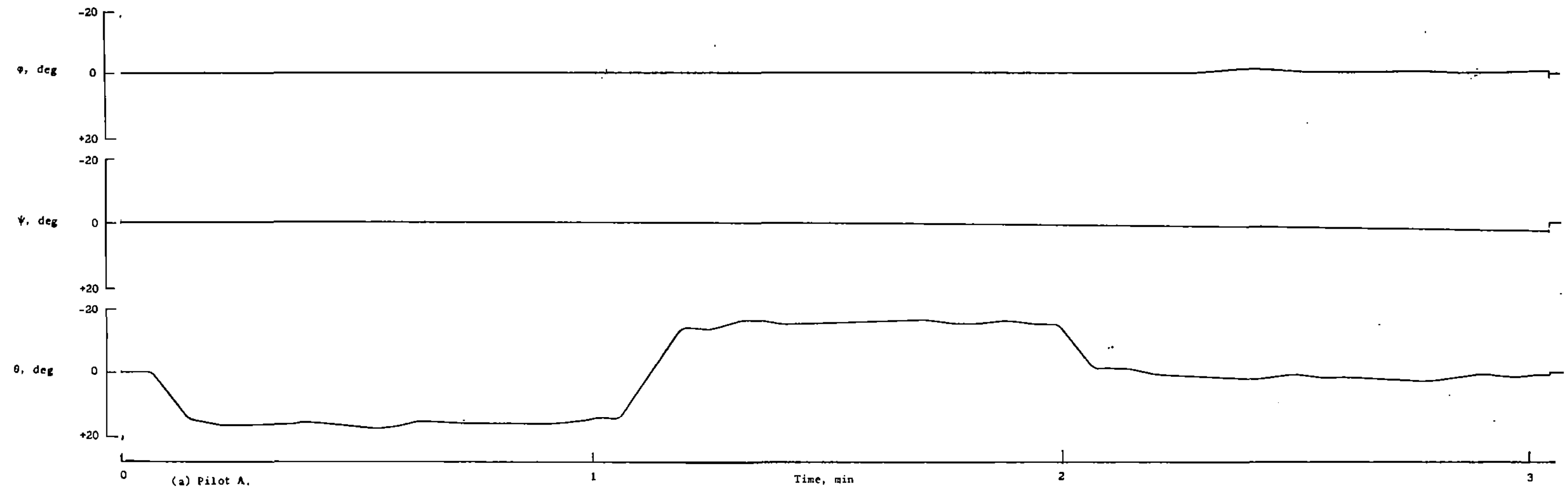
(b) Pilot B.

Figure 7.- Variation of thrust with time for task 1.

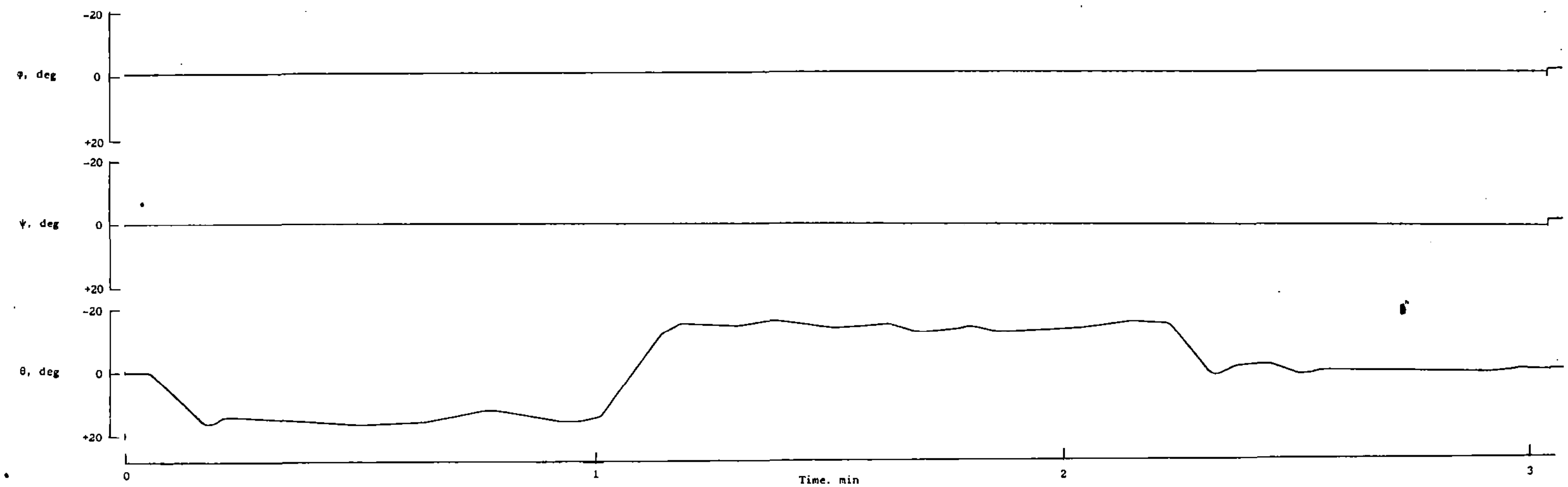


(c) Pilot C.

Figure 7.- Concluded.

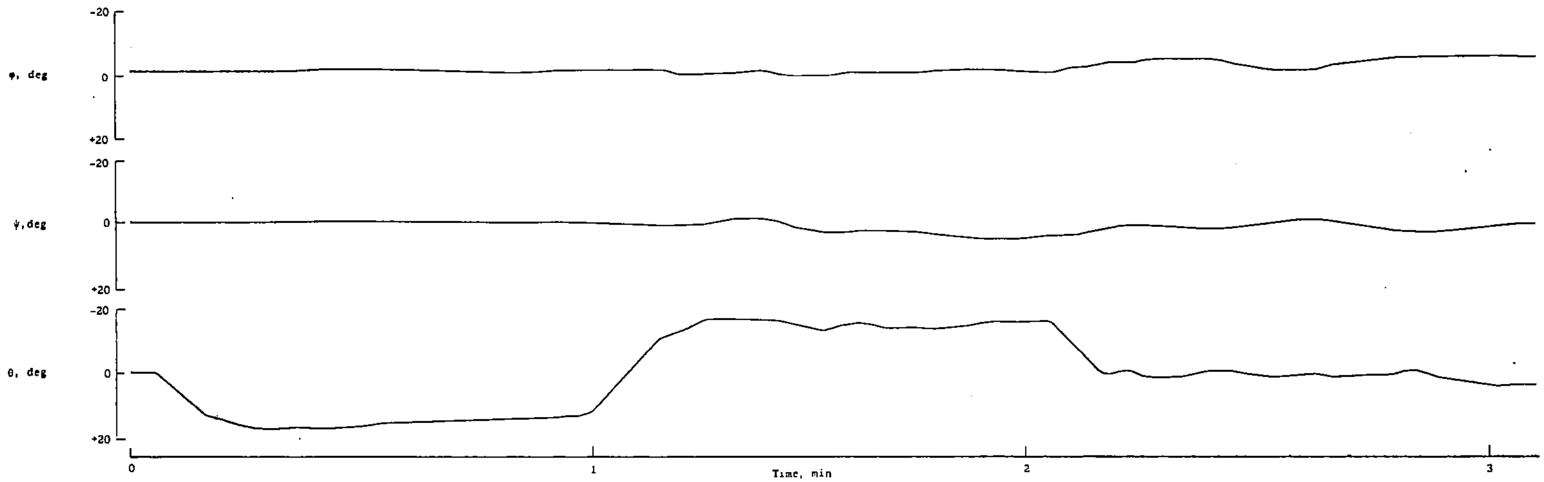


(a) Pilot A.



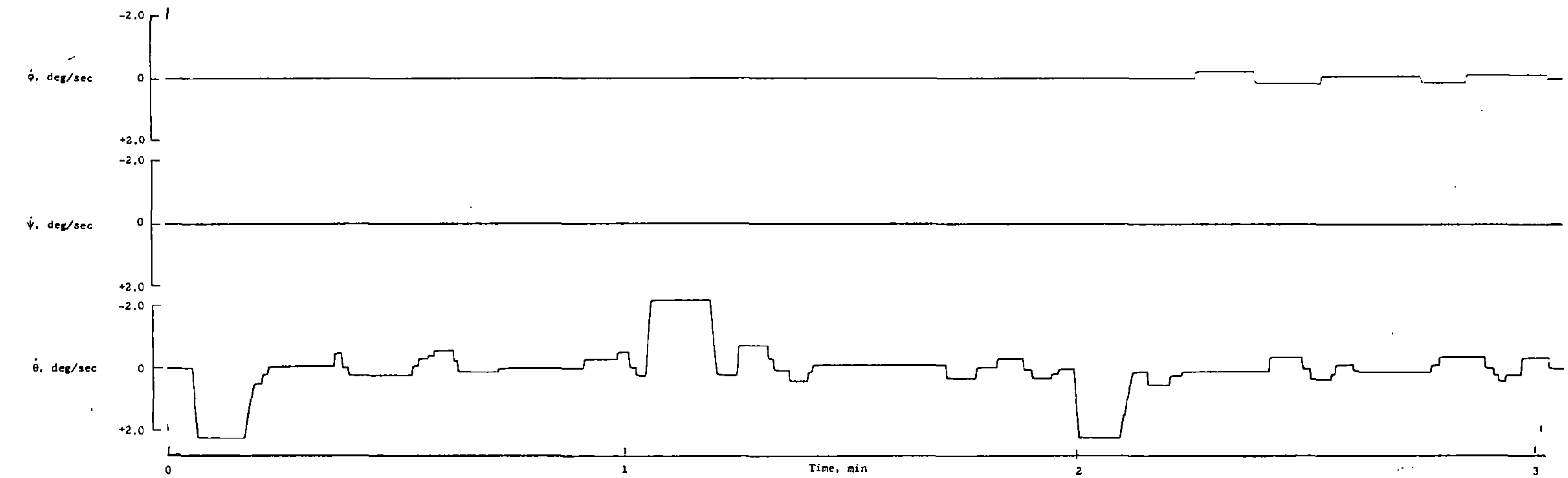
(b) Pilot B.

Figure 8.- Variation of attitude with time for task 2.

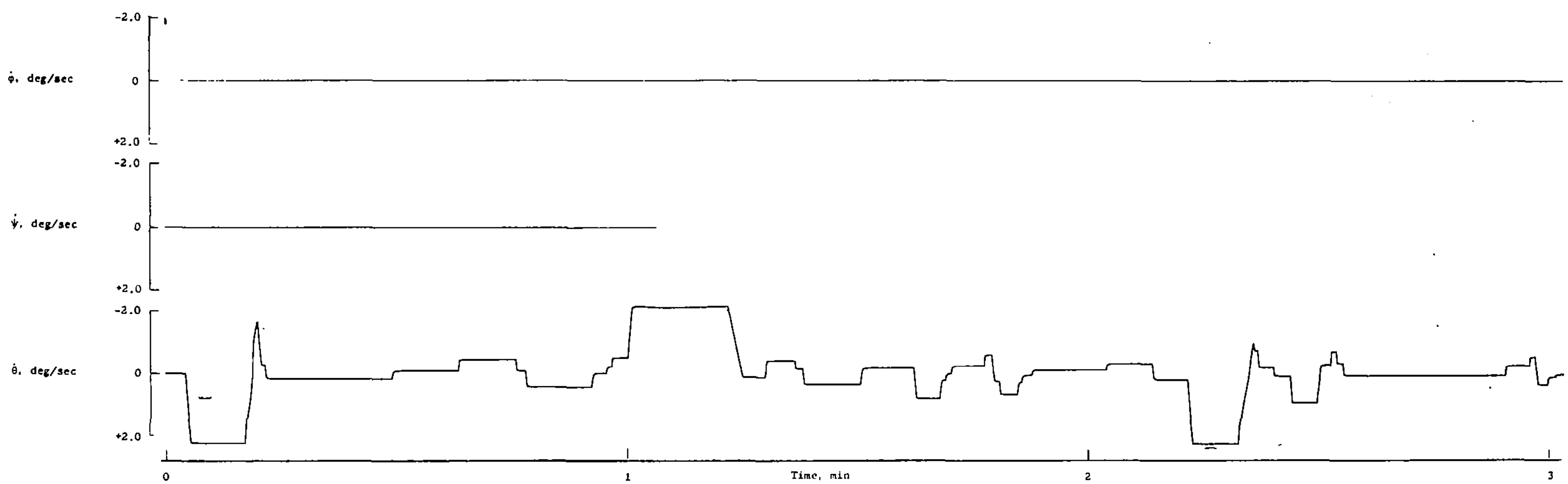


(c) Pilot C.

Figure 8.- Concluded.

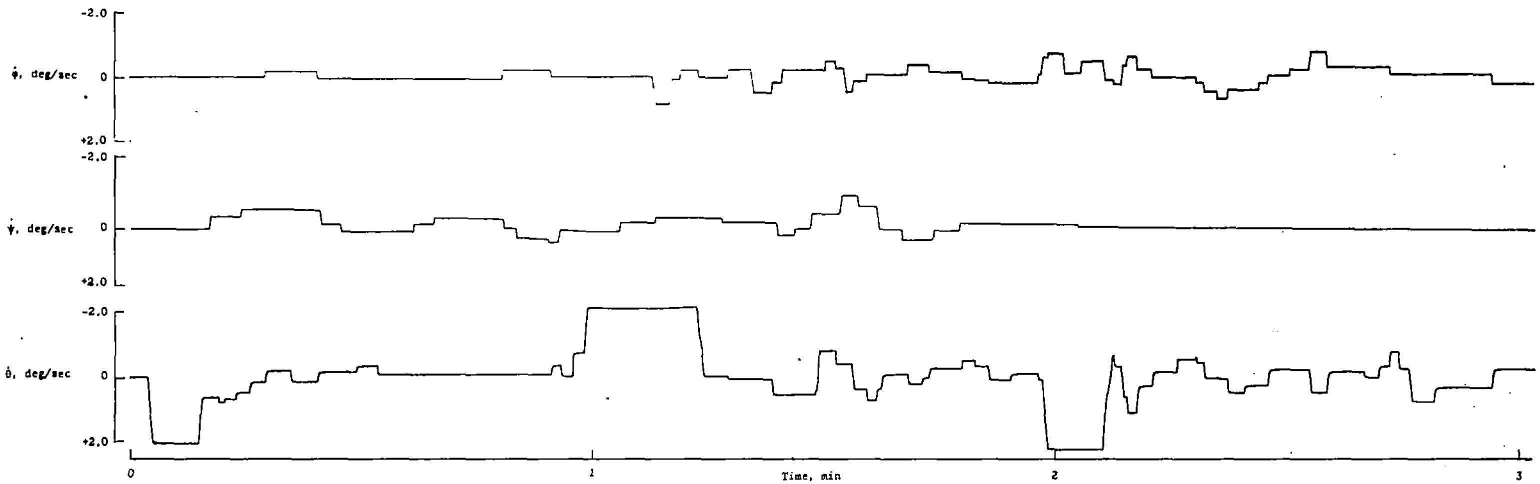


(a) Pilot A.



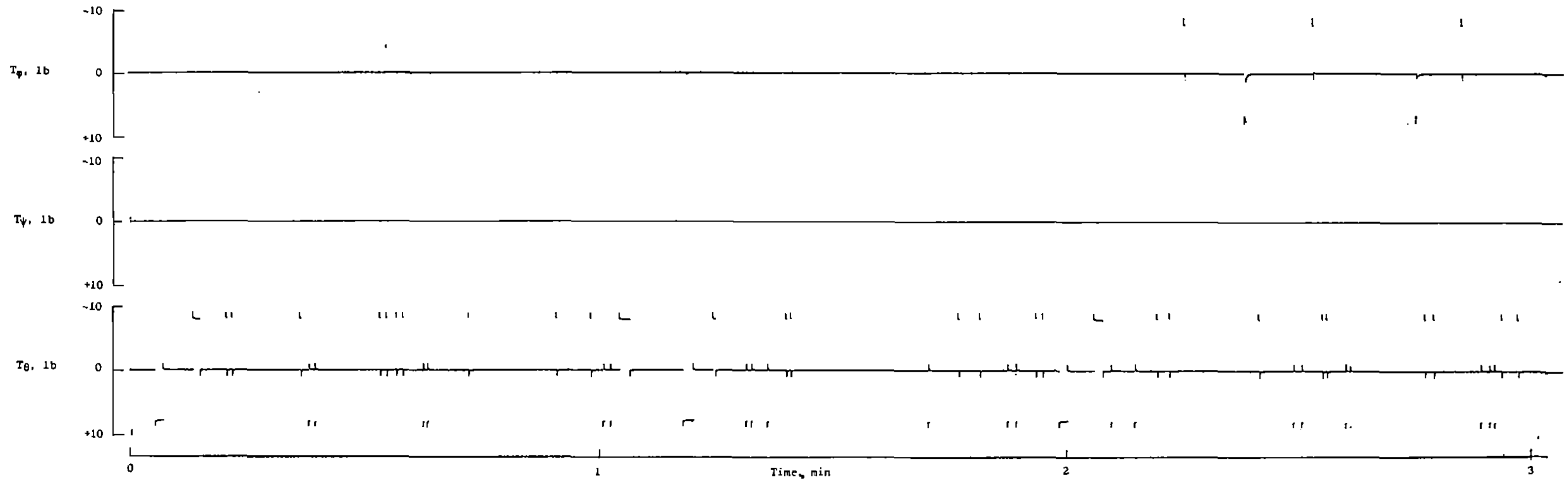
(b) Pilot B.

Figure 9.- Variation of angular velocity with time for task 2.

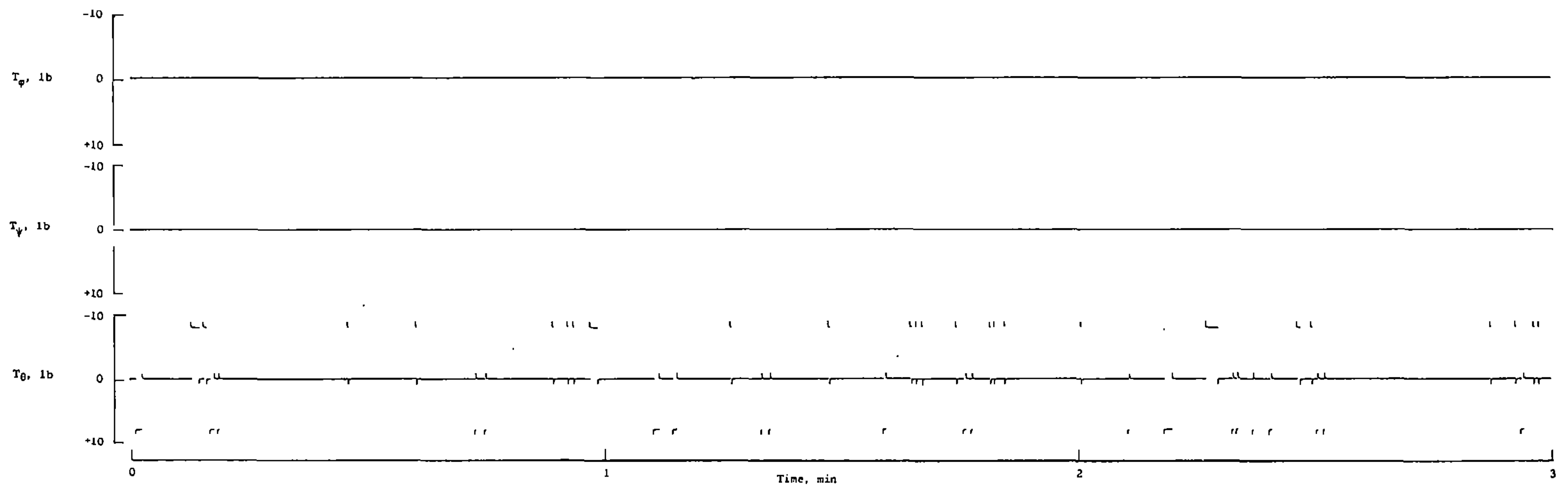


(c) Pilot C.

Figure 9.- Concluded.

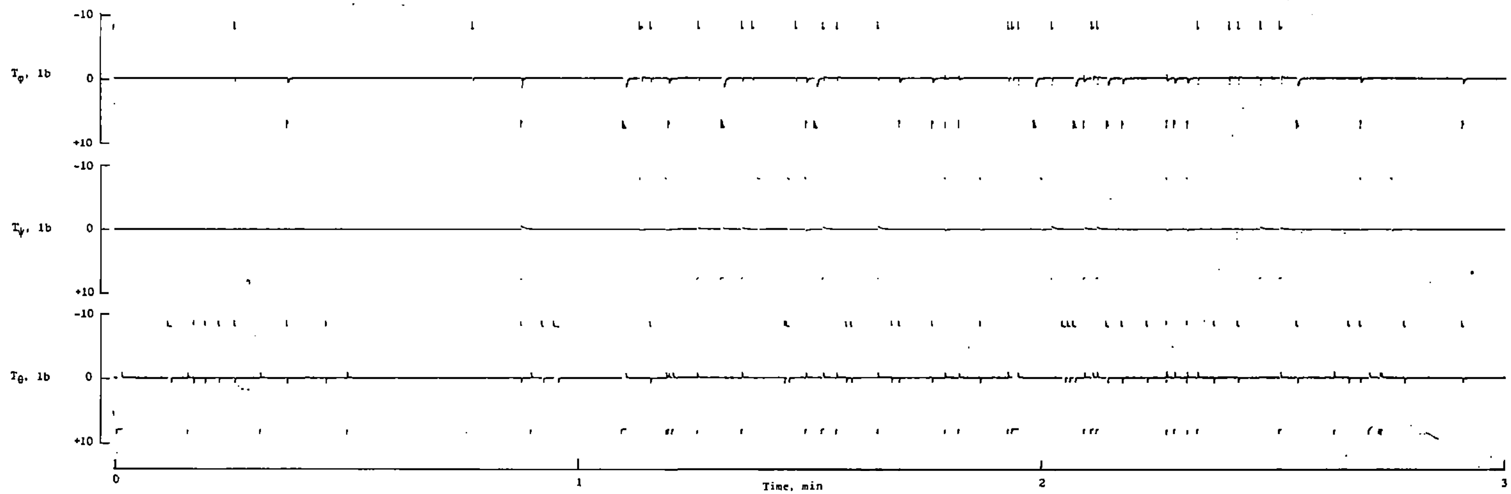


(a) Pilot A.



(b) Pilot B.

Figure 10.- Variation of thrust with time for task 2.



(c) Pilot C.

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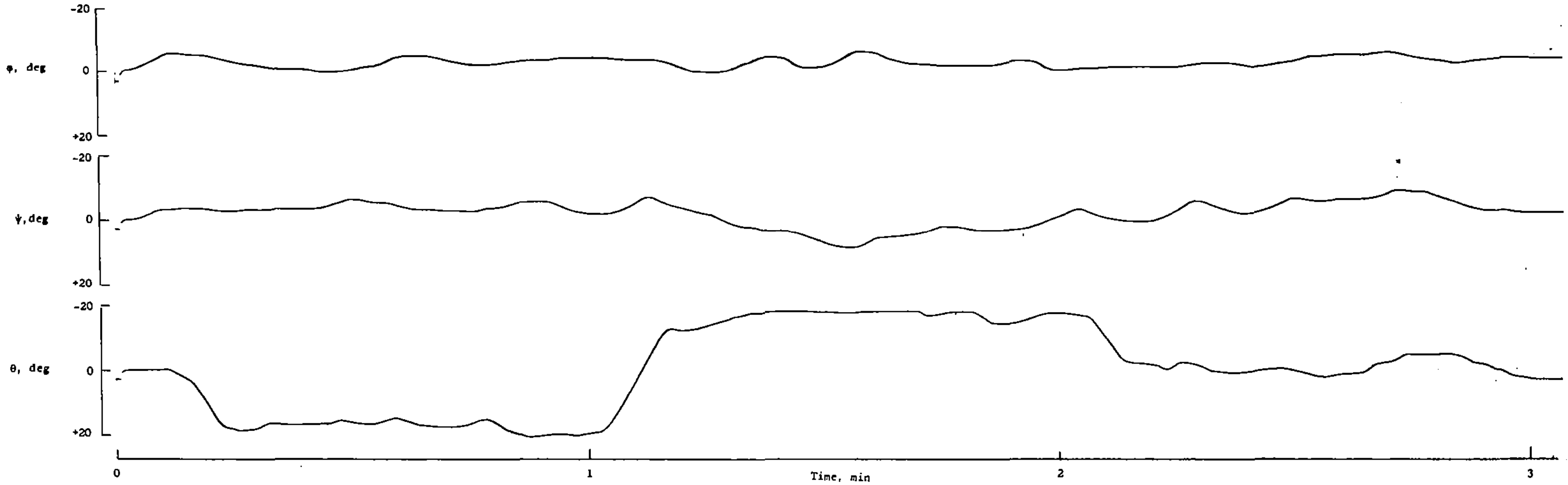
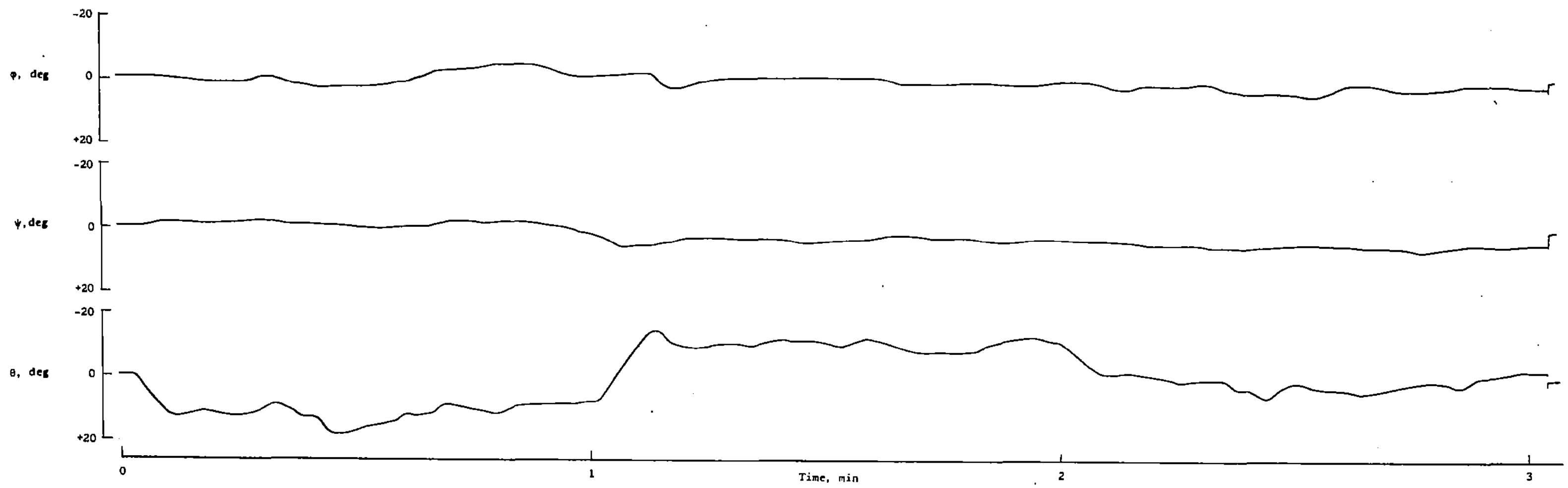
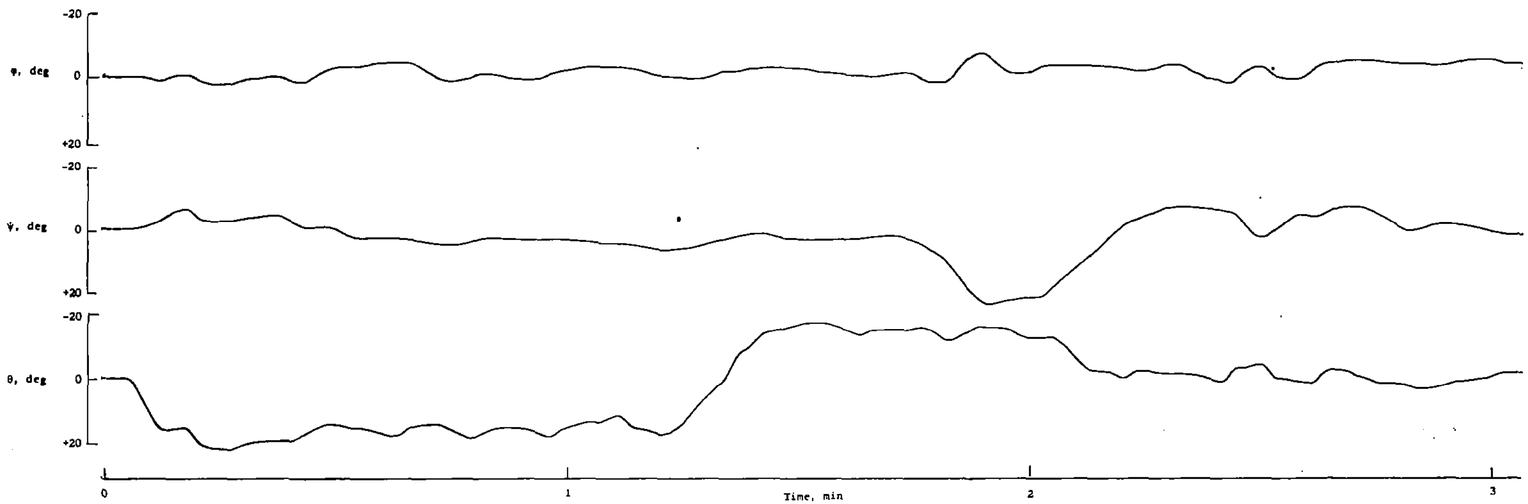


(a) Pilot A.



(b) Pilot B.

Figure 11.- Variation of attitude with time for task 3.



(c) Pilot C.

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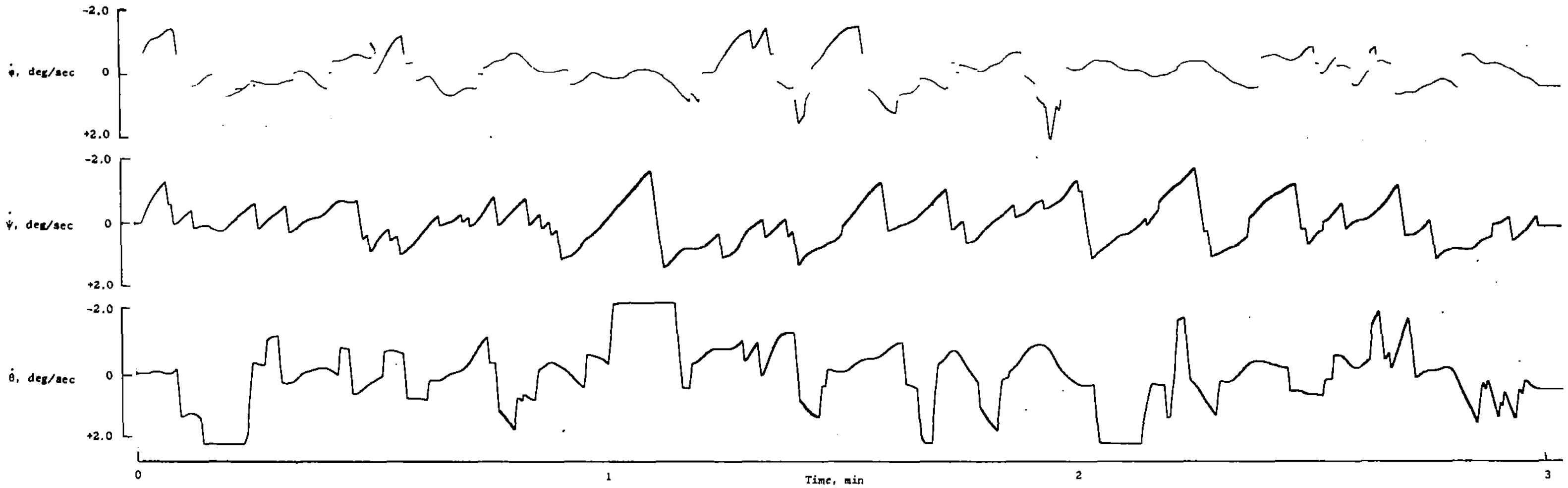
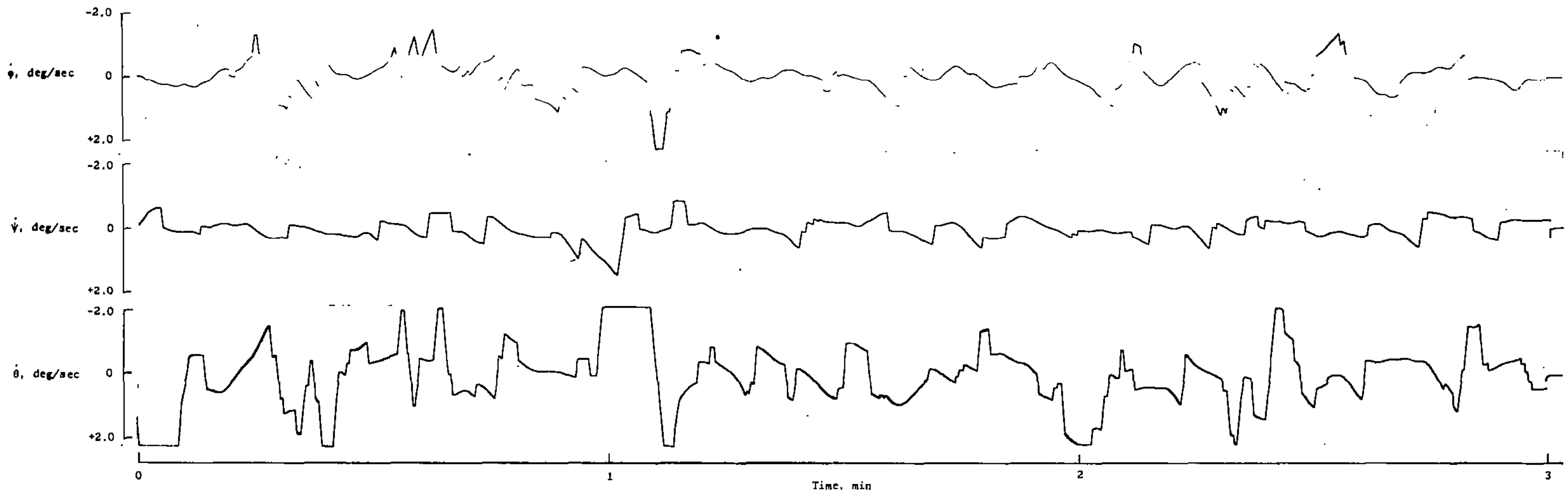
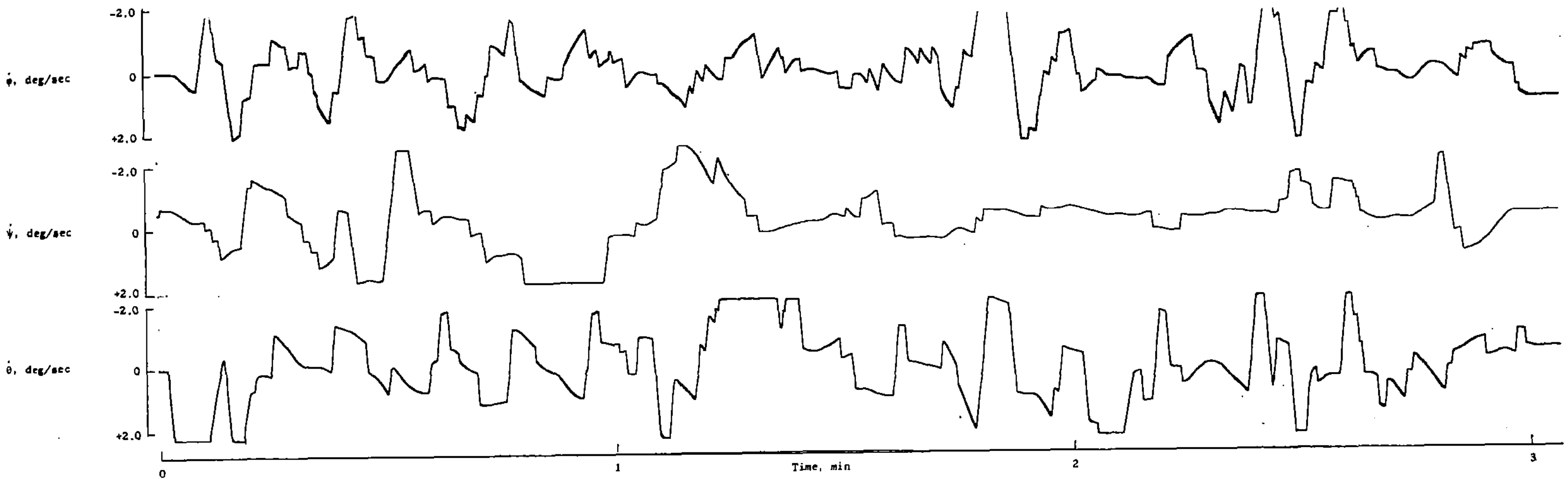


(a) Pilot A.



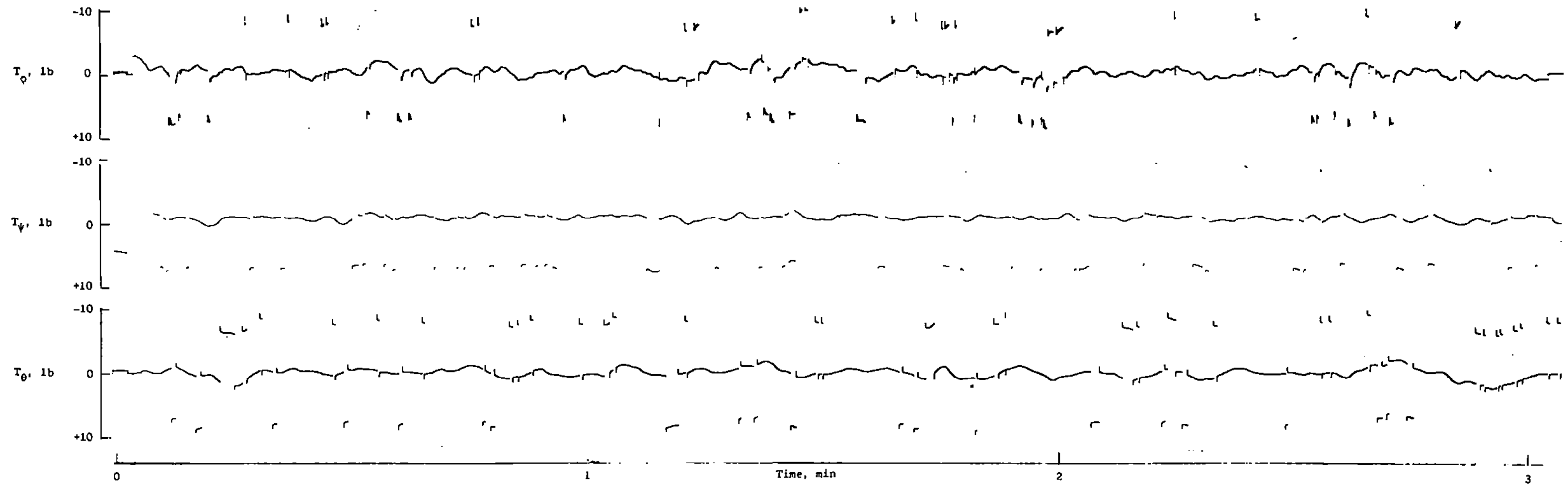
(b) Pilot B.

Figure 12.- Variation of angular velocity with time for task 3.

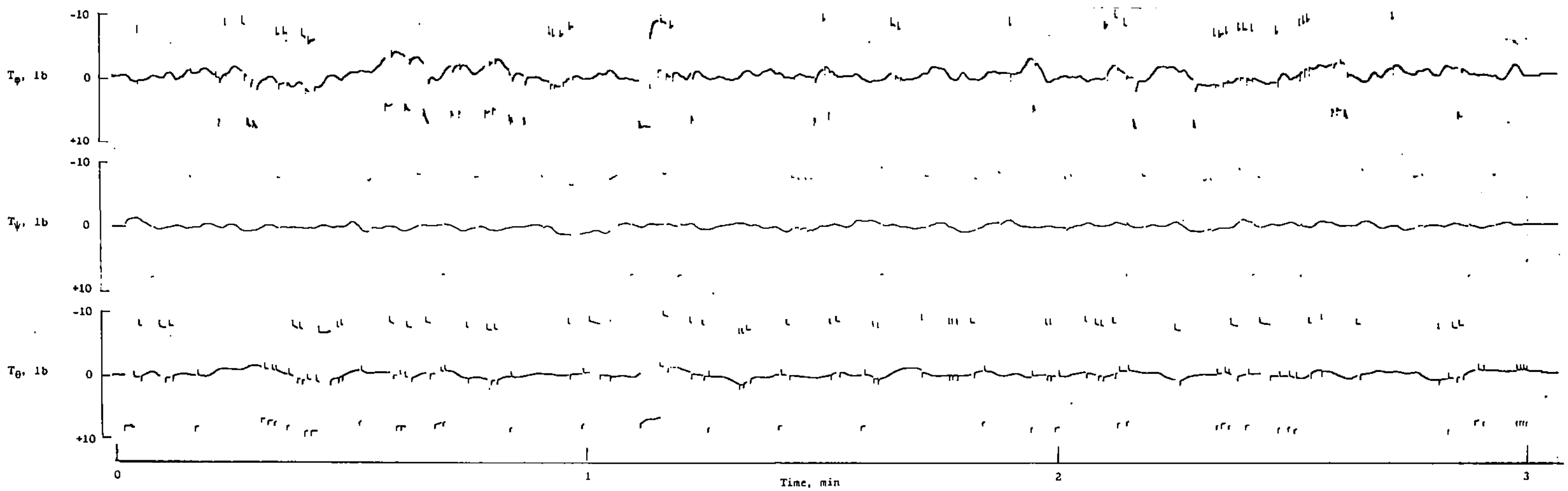


(c) Pilot C.

Figure 12.- Concluded.

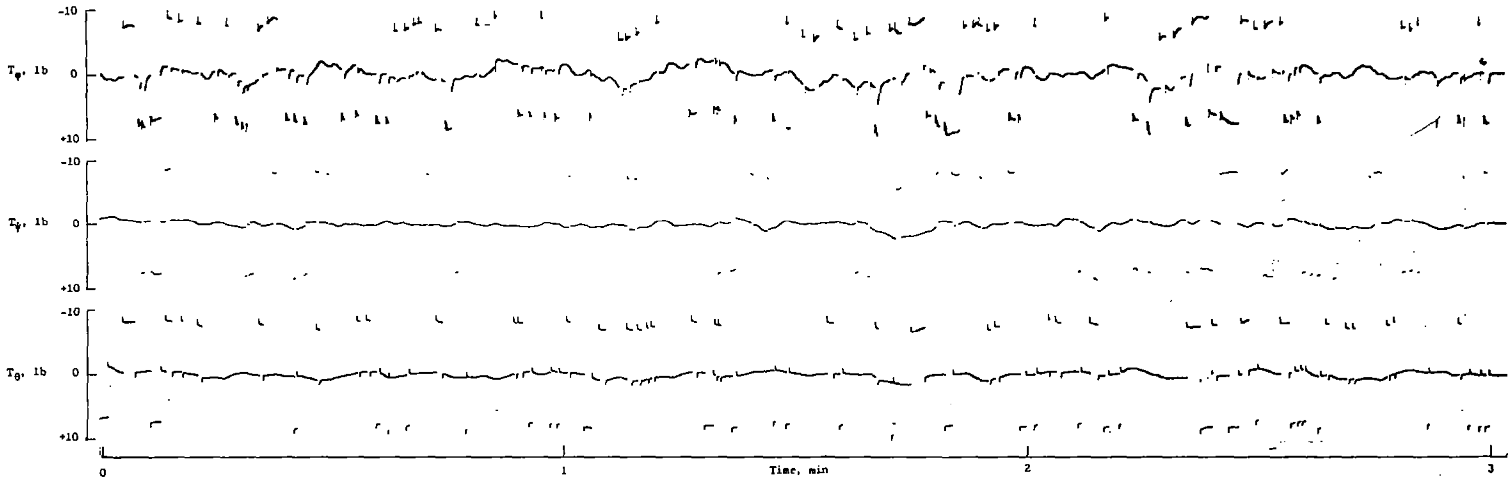


(a) Pilot A.



(b) Pilot B.

Figure 13.- Variation of thrust with time for task 3.



(c) Pilot C.

Figure 13.- Concluded.

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